management of resources becomes far more complex—it will have to maintain a database of all protocols, channel lists, and the locations for which they apply. The protocol will also require the development of algorithms and software to determine user assignments compatible with satellite resources and LMDS restrictions.

Transportable and mobile terminals are a potentially important area of business for emerging FSS systems, but the Bellcore protocol makes technical operation even more difficult for these systems. Transportable terminals are already important for uplinking TV at Ku-band, and we can expect demand for transportable service in the 27.5 to 29.5 GHz region. Mobile links from aircraft at these frequencies has already been demonstrated. For the Bellcore protocols to work with transportable and mobile satellite terminals, they must place a greater and entirely impractical burden upon the satellite control system, which must respond in a much more dynamic fashion.

5.4 ADMINISTRATIVE ISSUES OF IMPLEMENTATION

If a single, comprehensive protocol were designated as the official standard, it would still need continuous updates of LMDS spectrum use nationwide. This information must be maintained current, raising a quagmire of institutional issues. Would multiple LMDS providers (say M in number) each send an information database to the multiple FSS providers (say N in number)? This would require M times N exchanges of information on a regular schedule. Or would LMDS providers send the databases to the government or to an association of LMDS providers, which would have responsibility for integrating and distributing the databases?

In this process, there is a concern that the process be administered by a disinterested party. There will an natural tendency for LMDS providers to be excessive in protecting portions of the spectrum, and criteria for declaring potential interference are likely to be over-reaching. Also, when LMDS equipment is removed from service, it is easy to overlook removal from the list. The day-to-day process of management—or at least on-going oversight—should be in the hands of a disinterested government organization.

5.5 DEGRADATION IN EFFICIENT USE OF SPECTRUM BY FSS

The satellite communications community has steadily introduced technology and system concepts to make more efficient use of the spectrum. Spectrum-efficient modulation and coding now packs users in bandwidth while maintaining the power efficiency required for communicating from orbit. Furthermore, systems design have introduced bandwidth re-use through spatial isolation in different beam coverage areas and also by polarization isolation, with careful placement of users to limit interference between re-used bands. The development and implementation of these techniques have made C-band and Ku-band use increasing efficient.

Using these techniques can also result in greater spectrum efficiency in the 27.5 to 29.5 GHz bands, provided the restrictions that impede this efficiency are not applied. However, the Bellcore-proposed protocols do in fact apply restrictions that degrade spectrum efficiency. The protocols define channel bandwidths and location on the spectrum at the convenience of LMDS providers, meaning that bandwidth-efficient techniques employed by the satellite community will have to be discarded or modified to be consistent. Furthermore, satellite frequency re-use techniques will achieve less spectrum efficiency, since additional constraints on the placement of users must be considered.

SECTION 6

CONCLUSIONS

The Bellcore analysis fails to demonstrate the compatibility of LMDS and FSS in a common frequency band. Further, it does not support the Bellcore conclusion that the LMDS and the FSS can share the 27.5- to 29.5-GHz frequency band with 99.9 percent availability for both services.

A fundamental sharing problem arises because both LMDS and FSS services are intended for the same customer base. When FSS terminals and LMDS receivers are located in neighboring buildings (and sometimes even in the same household), the acceptable separation between the FSS terminal and the LMDS receiver will be meters, not kilometers. Under these conditions, the LMDS system improvements recommended by Bellcore will be of little help in mitigating the effects of interference.

The Bellcore analysis of LMDS availability, even with the modified LMDS system parameters, fails to demonstrate the compatibility of LMDS and FSS in a common frequency band. Several key factors lead to this conclusion:

The objective C/(N+I) of 13 dB of 99.9 percent is not achieved in the presence of 15 uniformly distributed Teledesic T1 terminals even when using the modified LMDS system parameters

The assumption that FSS terminal distribution will be uniform throughout the FSS spacecraft antenna beam area is flawed

LMDS availability in the presence of clustered Teledesic terminals (either T1 or 16 kbps) drops to the range of 99 percent to 94 percent

LMDS availability in the presence of clustered Spaceway T1 terminals can reasonably be expected to be on the order of 98 percent or less, not 99.9 percent

The Bellcore report does not address the availability of the subscriber-to-hub link; as the NRMC concluded, and as we show, this link represents a serious interference problem

The system cannot accommodate additional FSS networks

There are also flaws in some of the fundamental assumptions that Bellcore adopted for its analysis. For example, in computing availability, Bellcore averaged the degree of interference in areas of locally clustered active FSS transmitters with that in sparse activity areas, and computed the average with uniform weighting. It is inaccurate to accord areas of little usage the same importance as areas with significant usage. The significance of interference-prone areas (which are generally associated with a high density of LMDS and FSS users) should not be diluted by uniform averaging over areas that include remote, low-usage areas.

Bellcore's use of 99.9 percent as a value for system-wide availability is a misuse of a historically accepted short-term-outage criterion. LMDS system operators may well be willing to accept a < 0.1 percent system outage rate, but individual users who suddenly experience serious reception problems with television programs cannot be expected to be so accommodating.

It is likely that consumer political power and the right of LMDS users to retain service will effectively bar FSS system entry to urban and suburban areas containing LMDS systems.

The Bellcore report also contains a number of technical flaws:

It ignores interference between cells, and mis-models the number of LMDS cells in a Teledesic cell

It assumes that LMDS availability can be based on a C/(N+I) in the range of 8 to 13 dB with the consequence that some LMDS subscribers will experience marginal or unsatisfactory reception for long periods of time

The picture quality estimated by Bellcore as a function of received carrier-to-noise plus interference is at serious variance with CellularVision test results provided to the NRMC

The Bellcore report also assumes that LMDS subscriber antennas can be manufactured and maintained in a home or office environment with significantly better sidelobe performance than recommended by the ITU-R, an unrealistic assumption. Interference at levels greater than predicted will affect availability of LMDS to its subscribers.

FSS antenna sidelobe performance greatly improved over that considered by the NRMC, as suggested by Bellcore, is not achievable. The antennas cited in the report as examples of this improvement are not suitable because of their weight, size, cost, and inability to track satellites.

The Bellcore-proposed protocol contains several serious flaws. Based as it is on FSS use of guard bands between CellularVision video channels, the protocol would prevent CellularVision from achieving satisfactory availability on their subscriber-to-hub links. In addition, the Bellcore report did not consider the effect of additional FSS systems such as the Loral network and others on the protocol; we believe that adding these additional systems will render the Bellcore protocol unworkable.

Other flaws with the Bellcore protocol include:

- The protocol selectively places users in scattered frequency gaps, a practice totally incompatible with satellite technology and system designs

- The protocol addresses one or two specific LMDS systems and FSS systems in isolation, rather considering the more realistic scenario of multiple systems

- The protocol largely ignores the details and significant problems relating to the technical implementation and operation

- The protocol ignores the administrative issues and problems associated with implementation

- The protocol will significantly limit efforts in the efficient use of the spectrum by FSS

Based on our review of the Bellcore report and the other relevant material available, we can find no realistic method of sharing a frequency band between LMDS and FSS services. The Bellcore approach is not a feasible basis for establishing co-equal allocations for the FSS and LMDS in a common frequency band.

APPENDIX

FSS PHASED-ARRAY PERFORMANCE ESTIMATION

A phased-array antenna has been proposed for Teledesic uplink for rapid beam steering, when satellites hand-off a supercell. In the absence of a particular array design, we assumed a circular antenna with a minimum gain of 36 dBi at 29.4 GHz at the maximum scan of 50 degrees from boresight. To meet the gain, the antenna must be 14.8 inches in diameter. In order to avoid grating lobes at the maximum scan angle, the spacing is 0.262 inches between elements in an equilateral triangular grid. For this spacing, the array contains 2879 elements.

We assume the gain of the array rolls off as COS^1.3(theta), where theta is the steered angle off boresight. The array will have imperfections that cause amplitude and phase variations in the aperture field; these variations will tend to lower the gain and raise the radiation pattern sidelobes. We assume the RMS amplitude error is 1.6 dB and the RMS phase error is 5 degrees; we also include quantization error caused by a 4-bit phase shifter. As the array ages, elements will fail. In our calculations, we assume 5 percent of the elements have failed. We also include effects of an axial ratio of 4 dB, radome losses of 0.5 dB, polarizer losses of 0.25 dB, element interconnect losses of 0.5 dB, and a VSWR of 2.5.

The result of these assumptions is a gain of 38.5 dBi at broadside and 36.0 dBi at 50 degrees off broadside. The effective isotropic radiated power (EIRP) is 34.1 dBW at 50 degrees, and each element radiates a modest power of -6.5 dBm. The power dissipated is approximately 12.5 mW/inch^2, assuming a power-added-efficiency of 30 percent (the radiation pattern plots are normalized to the peak of the beam). Examining the broadside plot, the gain of the antenna near the horizon is approximately 50 to 60 dB below the peak for a gain of -10 dBi to -15 dBi. Note that the beamwidth for the 50-degree case is broader than that for the broadside case, and gain near the horizon is about 40 to 50 dB below the peak for a gain of -4 dBi to -14 dBi.

Figure 3. FSS Phased Array Gain at Broadside

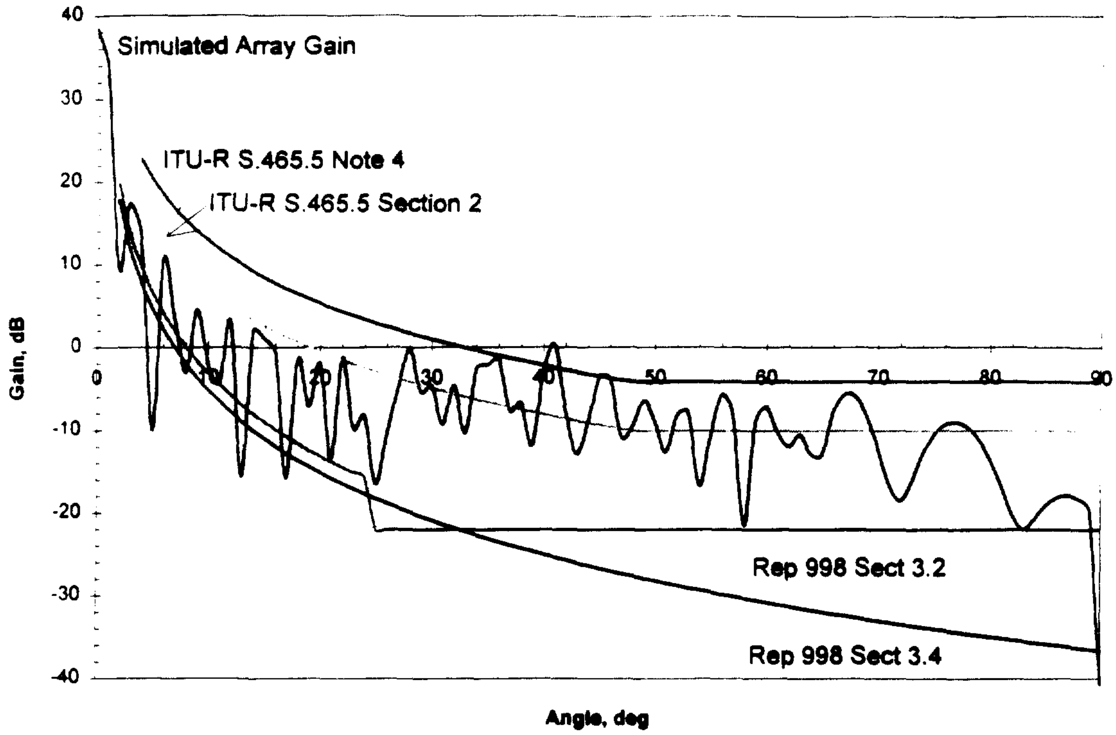

Figure 4. FSS Phased Array Gain at An Off Broadside Pointing Angle of 50°